**USING GEOCHEMICAL DATA TO ASSESS THE EVOLUTION OF THE WINONAITE-IAB PARENT BODY.** A.C. Hunt[1], G.K. Benedix[1,2], K. Kreissig[2], S. Hammond[3], S. Strekopytov[4] and M. Rehkamper[2]. [1]Impacts and Astromaterials Research Centre (IARC), The Natural History Museum, Department of Mineralogy, Cromwell Road, London, SW7 5BD, UK. [2]IARC, Imperial College London, Department of Earth Science and Engineering, South Kensington Campus, London, SW7 2AZ, UK. [3]The Open University, Department of Earth and Environmental Science, Walton Hall, Milton Keynes, MK7 6AA, UK. [4]The Natural History Museum, Department of Mineralogy, Cromwell Road, London, SW7 5BD, UK. Email: alison.hunt@nhm.ac.uk

**Introduction:** Primitive achondrites are a distinct class of meteorites that exhibit affinities with both chondrites and achondrites. Primitive achondrites, which include the acapulcoite–lodranite and winonaite–IAB groups, are characterised by chondritic mineral assemblages and bulk element compositions, but have textures which vary from high-grade metamorphic to those indicative of partial melting processes [1].

Winonaites are rare meteorites that are related to silicate inclusions in IAB iron meteorites via their oxygen isotope compositions [2]. They contain abundant Fe-Ni metal and troilite (up to 12.5 and 27.5 vol%, respectively [1]). These components are often present as veins cross-cutting silicate portions, which are interpreted as evidence for migration of a partial melt generated at the Fe, Ni–FeS cotectic (~950–980 °C [1, 3]). Heating of the winonaite parent body to at least this temperature is supported by two-pyroxene equilibration temperatures [1].

Additionally, winonaites have textures which imply varying degrees of planetary processing. In particular, they are characterised by heterogeneous grainsize and modal mineralogy. Some samples contain fine grained areas enriched in plagioclase and high-Ca pyroxene which have been suggested to represent areas of crystallised basaltic melt, whilst others contain coarse-grained olivine-rich regions which may represent the residues of melting [1]. Chondritic FeO-MgO-MnO systematics in the winonaites and IAB silicate inclusions suggest these samples are residues of low degrees of partial melting [4]. Variable whole-rock rare earth element (REE) abundances and patterns also suggest that some partial melting and fractionation has occurred [5, 6]. These discrepancies have been associated with heterogeneity in the winonaite samples and inconsistent sampling of REE-rich phosphates [5, 7].

Hypotheses for the origin of the winonaite-IAB parent body include: 1) localized impact melt pools [8]; 2) incomplete differentiation [9]; and 3) incomplete differentiation followed by catastrophic impact break-up and reassembly [10]. Ar-Ar and Hf-W ages for the winonaite-IAB body lend support to model 3 [11, 12]. In this project we aim to produce a comprehensive geochemical dataset to better interpret the evolution of the winonaite-IAB parent body. In particular, we will assess the extent of melting processes occurring across the parent body, and whether the winonaites represent residues, partial melts, or primitive, unmelted materials.

**Samples and Analytical Methods:** We have samples of 7 winonaites (Winona, Fortuna, QUE 94535, NWA 1463, Pontlyfni, Tierra Blanca and Hammadah al Hamra (HaH) 193) and 2 H ordinary chondrites that are used as standards (Ogi and Butsura). Full geochemical analyses can be conducted on <100 mg of powder, however as the winonaites are extremely heterogeneous samples, larger chips were crushed to help average out variations [7]. This also allows repeat digestions. Fusion crusts and weathered edges were removed from samples using a ceramic scalpel, before powdering by hand using an agate pestle and mortar.

Crushed samples were prepared for analysis by Inductively Coupled Plasma – Atomic Emission Spectroscopy (ICP-AES) at the Natural History Museum, London, to determine major and some minor elements. Major elements analysed by ICP-AES for this study include Mg, Al, Si, Ca, Ti, Mn and Fe. Major elements were determined by fusing ≥40 mg of sample with lithium metaborate flux in a ratio of 1:3, and dissolving the resultant glass bead in nitric acid before analysis with a Varian Vista Pro ICP-AES.

Minor and trace elements were analysed by Inductively Coupled Plasma – Mass Spectrometry (ICP-MS) and include, among others, Sc, Ni, Sr, Zr, Ba, Pb, Th, U and the REE. Samples were digested at Imperial College, London, using Teflon bombs. 50 mg of powdered sample was heated to 130 °C in a Teflon bomb with HF-$HNO_3$ for >24 hours before drying down. Samples were then refluxed with aqua regia followed by $HNO_3$-$HClO_4$ in order to destroy any remaining material. Blank concentrations for this procedure are negligible. Trace element concentrations were determined at The Open University by ICP-MS (Agilent 7500s). The precision of analyses made by ICP-MS is routinely better than ±2.5 % (2 s.d.) for elements heavier than Ga, and 2 – 3.5 % for elements lighter than Ga.

**Results and Discussion:** A plot of molar Mg/Si vs. Al/Si shows that the winonaites Fortuna, HaH 193 and

QUE 94535 plot with the Ordinary chondrites and most IAB silicate inclusions, implying they are primitive and unmelted (Fig. 1). Rare earth element data also show a relatively flat pattern, suggesting these samples have not been melted.

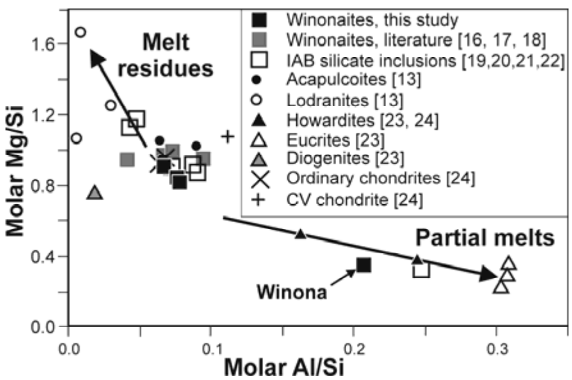


**Figure 1.** Plot of molar Mg/Si vs. Al/Si showing new winonaite data. Most winonaites and IAB silicate inclusions plot with the Ordinary chondrites, implying they are unmelted. Winona plots away from the winonaite group with meteorites interpreted to be partial melts, including the Howardites and Eucrites. For data sources see figure key.

However, unlike the other winonaites, on a plot of molar Mg/Si vs. Al/Si our sample of Winona plots with the Howardites and Eucrites, which are interpreted to represent partial melts (Fig. 1) [13]. This suggests Winona may also have undergone a degree of melting. Trace element data for the same split of Winona show the highest REE concentration recorded in a winonaite thus far (Fig. 2). In particular, unlike other analyses of Winona, our data show a positive Ce-anomaly. Ce-anomalies are often present in achondrites recovered from Antarctica, as a result of terrestrial weathering processes [14]. Although Winona was not recovered from a cold desert location (it was discovered in Arizona in 1928), we suggest that such a large Ce-anomaly can only be the result of terrestrial weathering. High concentrations of elements such as Ba also support this conclusion.

**Summary:** With the exception of Winona, which appears to be affected by extensive terrestrial weathering, the winonaites have primitive chemistries and plot with Ordinary chondrites on discrimination diagrams, implying they are essentially unmelted. Two-pyroxene temperatures, along with metal and sulfide textures, indicate that the winonaites reached at least the Fe-FeS eutectic (~975 °C), but new geochemical data suggest that they originate from a region of the winonaite-IAB parent body that did not reach the basaltic melting point (~1050 °C). However, textural evidence from some silicate inclusions in IAB irons indicates they originated through melting [10], implying heterogeneous heat distribution in the parent body.

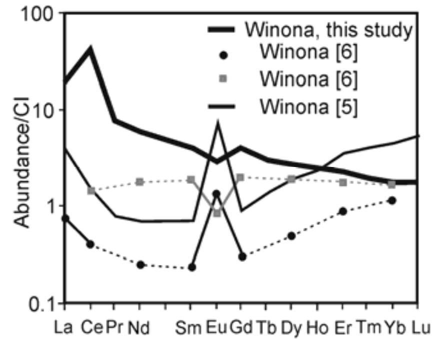


**Figure 2.** Winonaite REE abundance normalized to CI [15]. New analyses are compared to previous winonaite whole-rock data and calculated abundances. For data sources see figure key.

**References:** [1] Benedix, G.K. et al. (1998) *Geochim. Cosmochim. Acta, 62,* 2535-2553. [2] Clayton, R.N. and. Mayeda, T.K (1996) *Geochim. Cosmochim. Acta, 60,* 1999-2017. [3] Kubaschewski, O. (1982) *Iron-Binary Phase Diagram, Springer.* [4] Goodrich, C.A. and Delaney, J.S. (2000) *Geochim. Cosmochim. Acta, 64,* 149-160. [5] Floss, C., et al. (2008) *Meteoritics & Planet. Sci., 43,* 657-674. [6] Prinz, M. et al. (1980) *LPS XI,* 902-904. [7] Hunt, A.C. et al. (2011) *LPSC 43,* 1089 [8] Wasson, J.T. et al. (1980*) Z. Naturforsch., 35a,* 781-795. [9] Takeda et al. (1994) *Meteoritics, 29,* 830-842. [10] Benedix, G.K. et al. (2000) *Meteoritics & Planet. Sci., 35,* 1127-1141. [11] Vogel, N. and Renne, P. (2008) *Geochim. Cosmochim. Acta, 72,* 1231-1255. [12] Schulz, T. et al. (2010) *Geochim. Cosmochim. Acta, 74,* 1706-1718. [13] Mittlefehldt, D.W. et al. (1998) In *Planetary Materials* (Papike, ed.), Chapter 4, Reviews in Mineralogy, vol. 36. [14] Floss, C. and Crozaz, G. (1991) *Earth. Planet. Sci. Letters, 107,* 13-24. [15] Anders, E. and Grevesse, N. (1989) *Geochim. Cosmochim. Acta, 53,* 197-214. [16] Graham, A.L. et al. (1977) *Mineral. Mag., 41,* 201-210. [17] Mason, B. and Jarosewich, E. (1967) *Geochim. Cosmochim. Acta, 31,* 1097-1099. [18] King, E.A. et al. (1981) *Meteoritics, 16,* 229-237. [19] Wlotzka, F. and Jarosewich, E. (1977) *Smithsonian Contrib. Earth Sci., 19,* 104-125. [20] Kracher, A. (1974) In *Analyse Extraterrestrischen Materials* (Kiesl and Maliss, Jr., eds.), 315-326, Springer. [21] Jarosewich, E. (1967) *Cosmochim. Acta, 31,* 1103-1106. [22] Takeda, H. et al. (2000) *Cosmochim. Acta, 64,* 1311-1327. [23] Dodd R.T. (1981) *Meteorites: A Chemical-Petrologic Synthesis*. Cambridge Univ. Press. [24] Jarosewich, E. (1990) *Meteoritics, 25,* 323-337.